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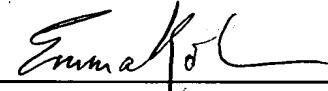
**GAS DIFFUSION SHOWER HEAD DESIGN FOR LARGE
AREA PLASMA ENHANCED CHEMICAL VAPOR
DEPOSITION**

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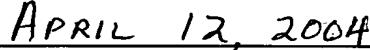
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**GAS DIFFUSION SHOWER HEAD DESIGN FOR LARGE AREA PLASMA
ENHANCED CHEMICAL VAPOR DEPOSITION**

BACKGROUND OF THE DISCLOSURE

Field of the Invention

[0001] Embodiments of the invention generally relate to a gas distribution plate assembly and method for distributing gas in a processing chamber.

Description of the Background Art

[0002] Liquid crystal displays or flat panels are commonly used for active matrix displays such as computer and television monitors. Plasma enhanced chemical vapor deposition (PECVD) is generally employed to deposit thin films on a substrate such as a transparent glass substrate (for flat panel) or semiconductor wafer. PECVD is generally accomplished by introducing a precursor gas or gas mixture into a vacuum chamber that contains a flat panel. The precursor gas or gas mixture is typically directed downwardly through a distribution plate situated near the top of the chamber. The precursor gas or gas mixture in the chamber is energized (e.g., excited) into a plasma by applying radio frequency (RF) power to the chamber from one or more RF sources coupled to the chamber. The excited gas or gas mixture reacts to form a layer of material on a surface of the flat panel that is positioned on a temperature controlled substrate support. Volatile by-products produced during the reaction are pumped from the chamber through an exhaust system.

[0003] Flat panels processed by PECVD techniques are typically large, often exceeding 370mm x 470mm and ranging over 1 square meter in size. Large area substrates approaching and exceeding 4 square meters are envisioned in the near future. Gas distribution plates utilized to provide uniform process gas flow over flat panels are relatively large in size, particularly as compared to gas distribution plates utilized for 200mm and 300mm semiconductor wafer processing.

[0004] Large gas distribution plates utilized for flat panel processing have a number of fabricating issues that result in high manufacturing costs. For

example, gas flow holes formed through the gas distribution plate are small in diameter relative to thickness of the gas distribution plate, for example a 0.016 inch diameter hole through a 1.2 inch thick plate, resulting in a high frequency of drill bit breakage during hole formation. Removal of broken drill bits is time consuming and may result in the entire gas distribution plate being scrapped. Additionally, as the number of gas flow holes formed through the gas distribution plate is proportional to the size of the flat panel, the great number of holes formed in each plate disadvantageously contributes to a high probability of trouble during plate fabrication. Moreover, the high number of holes coupled with the care required to minimize drill bit breakage results in long fabrication times, thereby elevating fabrication costs.

[0005] As the cost of materials for manufacturing the gas distribution plate is great, it would be advantageous to develop a gas distribution plate in a configuration that can be efficiently and cost effectively fabricated. Moreover, as the size of the next generation gas distribution plates is increased to accommodate processing flat panels in excess of 1.2 square meters, resolution of the aforementioned problems becomes increasingly important. While addressing the cost implications of the design of large gas distribution plates is important, performance attributes must not be overlooked. For example, the configuration, location and density of gas flow holes directly impact deposition performance, such as deposition rate and uniformity, and cleaning attributes, such as cleaning efficiency and residual cleaning chemical(s) in the process chamber.

[0006] Therefore, there is a need for an improved gas distribution plate assembly that reduces the manufacturing cost, and has good deposition and cleaning performance.

SUMMARY OF THE INVENTION

[0007] Embodiments of a gas distribution plate for distributing gas in a processing chamber are provided. In one embodiment, a gas distribution plate assembly for a plasma processing chamber comprises a diffuser plate having an upstream side and a downstream side, and a plurality of gas passages passing between the upstream and downstream sides, wherein at least one of

the gas passages has a right cylindrical shape for a portion of its length extending from the upstream side and a coaxial conical shape for the remaining length of the diffuser plate, the upstream end of the conical portion having substantially the same diameter as the right cylindrical portion and the downstream end of the conical portion having a larger diameter.

[0008] In another embodiment, a gas distribution plate assembly for a plasma processing chamber comprises a diffuser plate having an upstream side and a downstream side in the plasma process chamber that is coupled to a remote plasma source and the remote plasma source is coupled to a fluorine source, and a plurality of gas passages passing between the upstream and downstream sides, wherein at least one of the gas passages has a right cylindrical shape for a portion of its length extending from the upstream side and a coaxial conical shape for the remaining length of the diffuser plate, the upstream end of the conical portion having substantially the same diameter as the right cylindrical portion and the downstream end of the conical portion having a larger diameter.

[0009] In another embodiment, a gas distribution plate assembly for a plasma processing chamber comprises a diffuser plate having an upstream side and a downstream side, and a plurality of gas passages passing between the upstream and downstream sides, wherein at least one of the gas passages has a first right cylindrical shape for a portion of its length extending from the upstream side, a second coaxial right cylindrical shape with a smaller diameter connected to the first cylindrical shape, a coaxial conical shape connected to the second cylindrical shape for the remaining length of the diffuser plate, with the upstream end of the conical portion having substantially the same diameter as the second right cylindrical shape and the downstream end of the conical portion having a larger diameter.

[0010] In another embodiment, a gas distribution plate assembly for a plasma processing chamber comprises a diffuser plate having an upstream side and a downstream side in the plasma process chamber that is coupled to a remote plasma source and the remote plasma source is coupled to a fluorine source, and a plurality of gas passages passing between the upstream and downstream sides, wherein at least one of the gas passages has a first right

cylindrical shape for a portion of its length extending from the upstream side, a second coaxial right cylindrical shape with a smaller diameter connected to the first cylindrical shape, a coaxial conical shape connected to the second cylindrical shape for the remaining length of the diffuser plate, with the upstream end of the conical portion having substantially the same diameter as the second right cylindrical shape and the downstream end of the conical portion having a larger diameter.

[0011] In another embodiment, a method of depositing a thin film on a substrate comprises placing a substrate in a process chamber with a diffuser plate having an upstream side and a downstream side, and a plurality of gas passages passing between the upstream and downstream sides, wherein at least one of the gas passages has a right cylindrical shape for a portion of its length extending from the upstream side and a coaxial conical shape for the remaining length of the diffuser plate, the upstream end of the conical portion having substantially the same diameter as the right cylindrical portion and the downstream end of the conical portion having a larger diameter, and depositing a thin film on the substrate in the process chamber.

[0012] In another embodiment, a method of depositing a thin film on a substrate comprises placing a substrate in a process chamber with a diffuser plate having an upstream side and a downstream side, and a plurality of gas passages passing between the upstream and downstream sides, wherein at least one of the gas passages has a first right cylindrical shape for a portion of its length extending from the upstream side, a second coaxial right cylindrical shape with a smaller diameter connected to the first cylindrical shape, a coaxial conical shape connected to the second cylindrical shape for the remaining length of the diffuser plate, with the upstream end of the conical portion having substantially the same diameter as the second right cylindrical shape and the downstream end of the conical portion having a larger diameter, and depositing a thin film on the substrate in the process chamber.

[0013] In another embodiment, a method of cleaning a process chamber comprises placing a substrate in a process chamber, which is coupled to a remote plasma source and the remote plasma source is coupled to a fluorine source, with a diffuser plate having an upstream side and a downstream side,

and a plurality of gas passages passing between the upstream and downstream sides, wherein at least one of the gas passages has a right cylindrical shape for a portion of its length extending from the upstream side and a coaxial conical shape for the remaining length of the diffuser plate, the upstream end of the conical portion having substantially the same diameter as the right cylindrical portion and the downstream end of the conical portion having a larger diameter, depositing a thin film on the substrate in the process chamber, determining if the number of processed substrates having reached a pre-determined cleaning limit, repeating the steps of placing a substrate in the process chamber, depositing a thin film on the substrate and determining if the number of processed substrates has reached the pre-determined cleaning limit until the number of process substrates has reached the pre-determined cleaning limit, if the number of processed substrates has not reached the pre-determined cleaning limit, and cleaning the process chamber if the number of processed substrates has reached the pre-determined cleaning limit.

[0014] In yet another embodiment, a method of cleaning a process chamber comprises placing a substrate in a process chamber, which is coupled to a remote plasma source and the remote plasma source is coupled to a fluorine source, with a diffuser plate having an upstream side and a downstream side, and a plurality of gas passages passing between the upstream and downstream sides, wherein at least one of the gas passages has a first right cylindrical shape for a portion of its length extending from the upstream side, a second coaxial right cylindrical shape with a smaller diameter connected to the first cylindrical shape, a coaxial conical shape connected to the second cylindrical shape for the remaining length of the diffuser plate, with the upstream end of the conical portion having substantially the same diameter as the second right cylindrical shape and the downstream end of the conical portion having a larger diameter, depositing a thin film on the substrate in the process chamber, determining if the number of processed substrates has reached a pre-determined cleaning limit, repeating the steps of placing a substrate in the process chamber, depositing a thin film on the substrate and determining if the number of processed substrates has reached the pre-determined cleaning limit until the number of process substrates has reached the pre-determined

cleaning limit, if the number of processed substrates has not reached the pre-determined cleaning limit, and cleaning the process chamber if the number of processed substrates has reached the pre-determined cleaning limit.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The teachings of the present invention can be readily understood by considering the following detailed description in conjunction with the accompanying drawings, in which:

[0016] Figure 1 depicts a cross-sectional schematic view of a bottom gate thin film transistor.

[0017] Figure 2A is a schematic cross-sectional view of an illustrative processing chamber having one embodiment of a gas distribution plate assembly of the present invention.

[0018] Figure 2B depicts the bottom view of an embodiment of a gas diffuser plate of the current invention.

[0019] Figure 3 depicts a cross-sectional schematic view of a gas diffuser plate.

[0020] Figure 4A depicts a cross-sectional schematic view of an embodiment of a gas diffuser plate of the current invention.

[0021] Figure 4B depicts the top view of a section of an exemplary embodiment of a gas diffuser plate of the current invention.

[0022] Figure 4C depicts a cross-sectional schematic view of a variation of the gas diffuser plate design of Figure 4A.

[0023] Figure 5 shows the diffuser surface exposed to the process volume.

[0024] Figure 6 shows the process flow of depositing a thin film on a substrate in a process chamber with a gas diffuser plate and cleaning the process chamber.

[0025] Figure 7 shows the secondary ion mass spectrometer (SIMS) analysis of the fluorine content of SiN film of the Figure 3 and Figure 4A designs.

[0026] Figure 8A depicts a cross-sectional schematic view of a variation of the gas diffuser plate design of Figure 4A for thicker diffuser plate.

[0027] Figure 8B depicts a cross-sectional schematic view of another variation of the gas diffuser plate design of Figure 8A.

[0028] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures.

DETAILED DESCRIPTION

[0029] The invention generally provides a gas distribution plate assembly for providing gas delivery within a processing chamber. The invention is illustratively described below in reference to a plasma enhanced chemical vapor deposition system configured to process large area substrates, such as a plasma enhanced chemical vapor deposition (PECVD) system, available from AKT, a division of Applied Materials, Inc., Santa Clara, California. However, it should be understood that the invention has utility in other system configurations such as etch systems, other chemical vapor deposition systems and any other system in which distributing gas within a process chamber is desired, including those systems configured to process round substrates.

[0030] Figure 1 illustrates cross-sectional schematic views of a thin film transistor structure. A common TFT structure is the back channel etch (BCE) inverted staggered (or bottom gate) TFT structure shown in Figure 1. The BCE process is preferred, because the gate dielectric (SiN), and the intrinsic as well as n+ doped amorphous silicon films can be deposited in the same PECVD pump-down run. The BCE process shown here involves only 4 patterning masks. The substrate 101 may comprise a material that is essentially optically transparent in the visible spectrum, such as, for example, glass or clear plastic. The substrate may be of varying shapes or dimensions. Typically, for TFT applications, the substrate is a glass substrate with a surface area greater than about 500 mm². A gate electrode layer 102 is formed on the substrate 101. The gate electrode layer 102 comprises an electrically conductive layer that controls the movement of charge carriers within the TFT. The gate electrode layer 102 may comprise a metal such as, for example, aluminum (Al), tungsten (W), chromium (Cr), tantalum (Ta), or combinations thereof, among others. The gate electrode layer 102 may be formed using conventional deposition, lithography

and etching techniques. Between the substrate 101 and the gate electrode layer 102, there may be an optional insulating material, for example, such as silicon dioxide (SiO_2) or silicon nitride (SiN), which may also be formed using an embodiment of a PECVD system described in this invention. The gate electrode layer 102 is then lithographically patterned and etched using conventional techniques to define the gate electrode.

[0031] A gate dielectric layer 103 is formed on the gate electrode layer 102. The gate dielectric layer 103 may be silicon dioxide (SiO_2), silicon oxynitride (SiON), or silicon nitride (SiN), deposited using an embodiment of a PECVD system described in this invention. The gate dielectric layer 103 may be formed to a thickness in the range of about 100 Å to about 6000 Å.

[0032] A bulk semiconductor layer 104 is formed on the gate dielectric layer 103. The bulk semiconductor layer 104 may comprise polycrystalline silicon (polysilicon) or amorphous silicon ($\alpha\text{-Si}$), which could be deposited using an embodiment of a PECVD system described in this invention or other conventional methods known to the art. Bulk semiconductor layer 104 may be deposited to a thickness in the range of about 100 Å to about 3000 Å. A doped semiconductor layer 105 is formed on top of the semiconductor layer 104. The doped semiconductor layer 105 may comprise n-type (n^+) or p-type (p^+) doped polycrystalline (polysilicon) or amorphous silicon ($\alpha\text{-Si}$), which could be deposited using an embodiment of a PECVD system described in this invention or other conventional methods known to the art. Doped semiconductor layer 105 may be deposited to a thickness within a range of about 100 Å to about 3000 Å. An example of the doped semiconductor layer 105 is n^+ doped $\alpha\text{-Si}$ film. The bulk semiconductor layer 104 and the doped semiconductor layer 105 are lithographically patterned and etched using conventional techniques to define a mesa of these two films over the gate dielectric insulator, which also serves as storage capacitor dielectric. The doped semiconductor layer 105 directly contacts portions of the bulk semiconductor layer 104, forming a semiconductor junction.

[0033] A conductive layer 106 is then deposited on the exposed surface. The conductive layer 106 may comprise a metal such as, for example, aluminum (Al), tungsten (W), molybdenum (Mo), chromium (Cr), tantalum (Ta),

and combinations thereof, among others. The conductive layer 106 may be formed using conventional deposition techniques. Both the conductive layer 106 and the doped semiconductor layer 105 may be lithographically patterned to define source and drain contacts of the TFT. Afterwards, a passivation layer 107 may be deposited. Passivation layer 107 conformably coats exposed surfaces. The passivation layer 107 is generally an insulator and may comprise, for example, silicon dioxide (SiO_2) or silicon nitride (SiN). The passivation layer 107 may be formed using, for example, PECVD or other conventional methods known to the art. The passivation layer 107 may be deposited to a thickness in the range of about 1000 Å to about 5000 Å. The passivation layer 107 is then lithographically patterned and etched using conventional techniques to open contact holes in the passivation layer.

[0034] A transparent conductor layer 108 is then deposited and patterned to make contacts with the conductive layer 106. The transparent conductor layer 108 comprises a material that is essentially optically transparent in the visible spectrum and is electrically conductive. Transparent conductor layer 108 may comprise, for example, indium tin oxide (ITO) or zinc oxide, among others. Patterning of the transparent conductive layer 108 is accomplished by conventional lithographical and etching techniques.

[0035] The doped or un-doped (intrinsic) amorphous silicon ($\alpha\text{-Si}$), silicon dioxide (SiO_2), silicon oxynitride (SiON) and silicon nitride (SiN) films used in liquid crystal displays (or flat panels) could all be deposited using an embodiment of a plasma enhanced chemical vapor deposition (PECVD) system described in this invention.

[0036] Figure 2A is a schematic cross-sectional view of one embodiment of a plasma enhanced chemical vapor deposition system 200, available from AKT, a division of Applied Materials, Inc., Santa Clara, California. The system 200 generally includes a processing chamber 202 coupled to a gas source 204. The processing chamber 202 has walls 206 and a bottom 208 that partially define a process volume 212. The process volume 212 is typically accessed through a port (not shown) in the walls 206 that facilitate movement of a substrate 240 into and out of the processing chamber 202. The walls 206 and bottom 208 are typically fabricated from a unitary block of aluminum or other

material compatible with processing. The walls 206 support a lid assembly 210 that contains a pumping plenum 214 that couples the process volume 212 to an exhaust port (that includes various pumping components, not shown).

[0037] A temperature controlled substrate support assembly 238 is centrally disposed within the processing chamber 202. The support assembly 238 supports a glass substrate 240 during processing. In one embodiment, the substrate support assembly 238 comprises an aluminum body 224 that encapsulates at least one embedded heater 232. The heater 232, such as a resistive element, disposed in the support assembly 238, is coupled to an optional power source 274 and controllably heats the support assembly 238 and the glass substrate 240 positioned thereon to a predetermined temperature. Typically, in a CVD process, the heater 232 maintains the glass substrate 240 at a uniform temperature between about 150 to at least about 460 degrees Celsius, depending on the deposition processing parameters for the material being deposited.

[0038] Generally, the support assembly 238 has a lower side 226 and an upper side 234. The upper side 234 supports the glass substrate 240. The lower side 226 has a stem 242 coupled thereto. The stem 242 couples the support assembly 238 to a lift system (not shown) that moves the support assembly 238 between an elevated processing position (as shown) and a lowered position that facilitates substrate transfer to and from the processing chamber 202. The stem 242 additionally provides a conduit for electrical and thermocouple leads between the support assembly 238 and other components of the system 200.

[0039] A bellows 246 is coupled between support assembly 238 (or the stem 242) and the bottom 208 of the processing chamber 202. The bellows 246 provides a vacuum seal between the chamber volume 212 and the atmosphere outside the processing chamber 202 while facilitating vertical movement of the support assembly 238.

[0040] The support assembly 238 generally is grounded such that RF power supplied by a power source 222 to a gas distribution plate assembly 218 positioned between the lid assembly 210 and substrate support assembly 238 (or other electrode positioned within or near the lid assembly of the chamber)

may excite gases present in the process volume 212 between the support assembly 238 and the distribution plate assembly 218. The RF power from the power source 222 is generally selected commensurate with the size of the substrate to drive the chemical vapor deposition process.

[0041] The support assembly 238 additionally supports a circumscribing shadow frame 248. Generally, the shadow frame 248 prevents deposition at the edge of the glass substrate 240 and support assembly 238 so that the substrate does not stick to the support assembly 238. The support assembly 238 has a plurality of holes 228 disposed therethrough that accept a plurality of lift pins 250. The lift pins 250 are typically comprised of ceramic or anodized aluminum. The lift pins 250 may be actuated relative to the support assembly 238 by an optional lift plate 254 to project from the support surface 230, thereby placing the substrate in a spaced-apart relation to the support assembly 238.

[0042] The lid assembly 210 provides an upper boundary to the process volume 212. The lid assembly 210 typically can be removed or opened to service the processing chamber 202. In one embodiment, the lid assembly 210 is fabricated from aluminum (Al). The lid assembly 210 includes a pumping plenum 214 formed therein coupled to an external pumping system (not shown). The pumping plenum 214 is utilized to channel gases and processing by-products uniformly from the process volume 212 and out of the processing chamber 202.

[0043] The lid assembly 210 typically includes an entry port 280 through which process gases provided by the gas source 204 are introduced into the processing chamber 202. The entry port 280 is also coupled to a cleaning source 282. The cleaning source 282 typically provides a cleaning agent, such as disassociated fluorine, that is introduced into the processing chamber 202 to remove deposition by-products and films from processing chamber hardware, including the gas distribution plate assembly 218.

[0044] The gas distribution plate assembly 218 is coupled to an interior side 220 of the lid assembly 210. The gas distribution plate assembly 218 is typically configured to substantially follow the profile of the glass substrate 240, for example, polygonal for large area flat panel substrates and circular for wafers. The gas distribution plate assembly 218 includes a perforated area 216

through which process and other gases supplied from the gas source 204 are delivered to the process volume 212. The perforated area 216 of the gas distribution plate assembly 218 is configured to provide uniform distribution of gases passing through the gas distribution plate assembly 218 into the processing chamber 202. Gas distribution plates that may be adapted to benefit from the invention are described in commonly assigned United States Patent Application Serial Nos. 09/922,219, filed August 8, 2001 by Keller et al.; 10/140,324, filed May 6, 2002; and 10/337,483, filed January 7, 2003 by Blonigan et al.; United States Patent No. 6,477,980, issued November 12, 2002 to White et al.; and United States Patent Application Serial Nos. 10/417,592, filed April 16, 2003 by Choi et al., which are hereby incorporated by reference in their entireties.

[0045] The gas distribution plate assembly 218 typically includes a diffuser plate 258 suspended from a hanger plate 260. The diffuser plate 258 and hanger plate 260 may alternatively comprise a single unitary member. A plurality of gas passages 262 are formed through the diffuser plate 258 to allow a predetermined distribution of gas passing through the gas distribution plate assembly 218 and into the process volume 212. The hanger plate 260 maintains the diffuser plate 258 and the interior surface 220 of the lid assembly 210 in a spaced-apart relation, thus defining a plenum 264 therebetween. The plenum 264 allows gases flowing through the lid assembly 210 to uniformly distribute across the width of the diffuser plate 258 so that gas is provided uniformly above the center perforated area 216 and flows with a uniform distribution through the gas passages 262.

[0046] The diffuser plate 258 is typically fabricated from stainless steel, aluminum (Al), anodized aluminum, nickel (Ni) or other RF conductive material. The diffuser plate 258 is configured with a thickness that maintains sufficient flatness across the aperture 266 as not to adversely affect substrate processing. In one embodiment the diffuser plate 258 has a thickness between about 1.0 inch to about 2.0 inches. The diffuser plate 258 could be circular for semiconductor wafer manufacturing or polygonal, such as rectangular, for flat panel display manufacturing. Figure 2B shows an example of a diffuser plate 258 for flat panel display application being a rectangle with width 290 of about

30 inch and length 292 of about 36 inch. The sizes of the diffuser holes, the spacing of diffuser holes, and diffuser plate are not drawn to scale in Figure 2B.

[0047] Figure 3 is a partial sectional view of the diffuser plate 258 that is described in commonly assigned United States Patent Application Serial No. 10/227,483, titled "Tunable Gas Distribution Plate Assembly", filed on January 7, 2003. For example, for a 1080 in² (e.g. 30 inches X 36 inches) diffuser plate, the diffuser plate 258 includes about 16,000 gas passages 262. For larger diffuser plates used to process larger flat panels, the number of gas passages 262 could be as high as 100,000. The gas passages 262 are generally patterned to promote uniform deposition of material on the substrate 240 positioned below the diffuser plate 258. Referring to Figure 3, in one embodiment, the gas passage 262 is comprised of a restrictive section 302, a flared connector 303, a center passage 304 and a flared opening 306. The restrictive section 302 passes from the first side 318 of the diffuser plate 258 and is coupled to the center passage 304. The center passage 304 has a larger diameter than the restrictive section 302. The restrictive section 302 has a diameter selected to allow adequate gas flow through the diffusion plate 258 while providing enough flow resistance to ensure uniform gas distribution radially across the perforated center portion 310. For example, the diameter of the restrictive section 302 could be about 0.016 inch. The flared connector 303 connects the restrictive section 302 to the center passage 304. The flared opening 306 is coupled to the center passage 304 and has a diameter that tapers radially outwards from the center passage 304 to the second side 320 of the diffuser plate 258. The flared openings 306 promote plasma ionization of process gases flowing into the processing regions 212 and 214. Moreover, the flared openings 306 provide larger surface area for hollow cathode effect to enhance plasma discharge.

[0048] As mentioned earlier, large gas distribution plates utilized for flat panel processing have a number of fabricating issues that result in high manufacturing costs. The manufacturing cost of the quad-aperture diffuser plate design in Figure 3 is relatively high since it requires four drilling steps to drill restrictive section 302, flared connector 303, center passage 304 and flared opening 306 to create each gas passage 262 and the large number of gas

passages 262, for example about 16,000 for a 30 inches X 36 inches (or 1080 inch²) diffuser plate.

[0049] Figure 4A is a partial sectional view of the diffuser plate 258 of the current invention. The diffuser plate 258 includes about 12,000 gas passages 262 for a 30 inches X 36 inches (or 1080 inch²) diffuser plate. The gas passage 262 is generally patterned to promote uniform deposition of material on the substrate 240 positioned below the diffuser plate 258. Referring to Figure 4A, in one embodiment, the gas passage 262 is comprised of a restrictive section 402, and a conical opening 406. The restrictive section 402 passes from the first side 418 of the diffuser plate 258 and is coupled to the conical opening 406. The restrictive section 402 has a diameter between about 0.030 inch to about 0.070 inch, selected to allow adequate gas flow through the diffusion plate 258 while providing enough flow resistance to ensure uniform gas distribution radially across the perforated center portion 410. The edges of the restrictive section of the diffuser holes on the first side 418 of the diffuser plate 258 could be rounded. The conical opening 406 is coupled to the restrictive section 402 and flares radially outwards from the restrictive section 402 to the second side 420 of the diffuser plate 258. The conical opening 406 has a diameter between about 0.2 inch to about 0.4 inch on the second side 420 of the diffuser plate 258. The second side 420 faces the surface of the substrate. The flaring angle 416 of the conical opening 406 is between about 20 to about 35 degrees.

[0050] The spacing between flared edges of adjacent gas passages 262 should be kept as small as possible. The flared edges could be rounded. An example of the spacing is 0.05 inch. The maximum spacing between flared edges of adjacent gas passages 262 is about 0.5 inch. The total restriction provided by the restrictive section 402 directly affects the back pressure upstream of the diffuser plate 258, and accordingly should be configured to prevent re-combination of disassociated fluorine utilized during cleaning. The ratio of the length (411) of the restrictive section 402 to the length (412) of the conical opening 406 is between about 0.8 to about 2.0. The total thickness of diffuser plate, which equals the summation of length 411 and length 412, is between about 0.8 inch to about 1.6 inch. The conical openings 406 promote plasma ionization of process gases flowing into the processing regions 212 and

214. An example of the quad-aperture gas passage design has the restrictive section 402 diameter at 0.042 inch, the length of the restrictive section 402 at 0.0565 inch, the conical opening 406 diameter on the second side 420 of the diffuser plate 258 at 0.302 inch, the length of the conical opening section at 0.0635 inch, and the flaring angle 416 at 22°. The total thickness of the exemplary diffuser plate is 1.2 inches.

[0051] Figure 4B shows a section of an exemplary embodiment of a hexagonal close pack gas diffuser plate 258. The holes 450 (or gas passages 262 described earlier) are arranged in a pattern of face centered hexagons 460. The size of diffuser holes, and the spacing of diffuser holes are not drawn to scale in Figure 4B. However, other patterns of gas passages 262 arrangement (or holes 450), such as concentric circles, can also be used.

[0052] Figure 4C shows an alternative design to the design shown in Figure 4A. During the manufacturing process of machining the restrictive section 402 and the flared section 406, a flared connecting section 405 could be created by using a different drill to round up (or remove) the burrs left during drilling sections 402 and 406. Aside from the addition of this connecting section 405, the rest of design attributes of Figure 4C are the same as the design attributes of Figure 4A.

[0053] Comparing the quad-aperture design in Figure 3 and the funnel design in Figure 4A, one can see that the funnel design is easier to manufacture than the quad-aperture design. Funnel design in Figure 4A requires drilling of 2 sections which include the restrictive section 402 and the conical section 406; while the quad-aperture design in Figure 3 requires drilling of 4 sections: the restrictive section 302, flared connector 303, center passage 304 and flared opening 306. Drilling of 2 sections to meet the manufacturing specification is much easier than drilling of 4 sections to meet the manufacturing specification. The funnel design in Figure 4A also would have higher manufacturing yield than the quad-aperture design in Figure 3 due to lower total number of holes. For example, for a 1080 in² (e.g. 30 inches X 36 inches) diffuser plate, the funnel design has about 12,000 holes, while the quad-aperture design has about 16,000 holes. The funnel design diffuser plate has about 30% less holes than the quad-aperture design diffuser plate. In addition, the funnel design in Figure

4A has fewer particle problems than the quad-aperture design in Figure 3 due to its relative simplicity in removing broken drill bits from the larger restrictive section 402 (e.g. 0.040 inch and 0.055 inch), compared to the smaller restrictive section 302 (e.g. 0.016 inch).

[0054] In addition to higher manufacturing yield and fewer particle problems, the total surface area of the diffuser plate 258 exposed to the process volume 212 of the funnel design is less than the quad-aperture design, which would reduce the amount of residual fluorine on the diffuser plate (or shower head) from the cleaning process. Reduced residual fluorine could greatly reduce the fluorine incorporation in the film during deposition process. Incorporation of fluorine in the gate dielectric (or insulating) film, such as SiO₂, SiON or SiN, generates defect centers that degrade thin film transistor (TFT) device performance, such as V_t (threshold voltage) shift and I_{on} (drive current) reduction. It has been found that if the incorporated contaminants of a gate dielectric film, such as SiO₂, SiON or SiN, exceed 1E20 atom/cm³, the TFT device performance could be severely affected. Besides, the quad-aperture design also creates higher back pressure when the cleaning gas is flowing through the gas distribution plate. The disassociated fluorine utilized to clean the plate has an increased propensity to recombine when the back pressure is higher, disadvantageously diminishing cleaning effectiveness.

[0055] A film deposition chamber requires periodic cleaning to reduce the film build up, which might flake off to create particle problems, in the process chamber. An example of the cleaning process is the remote plasma source (RPS) clean, which utilizes fluorine containing plasma, generated from fluorine containing gases, such as NF₃, SF₆, F₂, C₂F₆, C₃F₆ or C₄F₈O etc., to clean. After the cleaning step, a purge gas is used to purge out residual fluorine; however, some residual fluorine species might remain on the chamber and diffuser plate surface areas. The darkened lines (501) in Figure 5 show the funnel design diffuser surface exposed to the process volume 212. Table 1 compares the total exposed surface areas of two funnel designs (0.040 inch and 0.055 inch restrictive section diameters) and a quad-aperture design. The diameter of the flared end of both funnel designs is 0.302 inch and the flaring angle is 22°. The restrictive section 402 length for both funnel designs is 0.565

inch, while the length of the flared opening 406 for both designs is 0.635 inch. As for the quad-aperture design, the diameter of the restrictive section 302 is 0.016 inch, the diameter of the center passage 304 is 0.156 inch, the large diameter of the flared opening 306 is 0.25 inch and the flaring angle is 22°, the length of restrictive section is 0.046 inch, the length of the flared connector 303 is 0.032 inch, the length of the center passage 304 is 0.88 inch and the length of the flared opening 306 is 0.242 inch. The quad-aperture design has highest number of diffuser holes and highest total diffuser surface area. Both 0.040 inch and 0.055 inch funnel designs have relatively close total exposed diffuser surface areas, which are about half the total exposed diffuser surface area of the quad-aperture design.

Diffuser Type	Number of diffusers on a 30 X 36 inch ² diffuser plate	Total exposed diffuser surface area (inch ²)
Quad-aperture	16188	10594
0.055 inch Funnel	11824	5352
0.040 inch Funnel	11824	5666

Table 1 compares the total exposed surface areas of two funnel designs (0.040 inch and 0.055 inch restrictive section diameters) and a quad-aperture design.

[0056] Figure 6 shows an example of a process flow 600 of depositing a thin film on a substrate in a process chamber with a gas diffuser plate and cleaning the process chamber when cleaning is required. The process starts at step 601, followed by step 602 of placing a substrate in a process chamber with a diffuser plate. Step 603 describes depositing a thin film on the substrate in the process chamber. After step 603, the system decides whether the number of processed substrates has reached a pre-determined cleaning limit at step 604. The pre-determined cleaning limit could be 1 substrate or more than 1 substrate. If the cleaning limit has not been reached, the process sequence goes back to step 602 of placing another substrate in the process chamber. If the cleaning limit has reached the pre-determined cleaning limit, the process sequence goes to step 605 of cleaning the process chamber. After chamber

cleaning at step 605, the system decides whether the number of total processed substrates has reached a pre-determined limit. If the cleaning limit has not been reached, the process sequence goes back to step 601 of starting the deposition process. If the cleaning limit has been reached the pre-determined limit, the deposition process stops at step 607. Process flow 600 is only used as an example to demonstrate the concept. The invention can also apply to process flows that involves other process steps or sequences, but fit into the general concept of deposition and cleaning.

[0057] Figure 7 shows the secondary ion mass spectrometer (SIMS) analysis of the fluorine content of film stacks, which contain SiN film, deposited with diffuser plates of the two designs. The film stack analyzed includes about 500 Å phosphorus doped (n+) amorphous silicon film, about 2200 Å amorphous silicon film, followed by about 4500 Å silicon nitride film on a glass substrate. The amorphous silicon and the silicon nitride films have been sequentially deposited with the same diffuser plate (or shower head) in the same PECVD chamber. Curve 701 shows the fluorine content of the 0.055 inch funnel design in the SiN film (less than 1E18 atom/cm³) is more than one order of magnitude lower than the films processed with the quad-aperture design diffuser plate (curve 702, about 5E19 atom/cm³). The lower fluorine content resulting from the funnel design is possibly due to lower total surface area of the diffuser plate 258 exposed to the process volume 212 compared to the quad-aperture design.

[0058] Chamber cleaning is accomplished by remote plasma source (RPS) clean which uses the fluorine radicals (F*) generated from fluorine-containing gases, such as NF₃, SF₆, F₂, C₂F₆, C₃F₆ or C₄F₈O etc. The fluorine-containing gas (or gases) could be diluted by an inert gas, such as argon (AR), to help sustain the plasma. However, the inert gas is optional. Generally, the cleaning process is performed with inert gas flowing at between about 0 slm to about 6 slm, fluorine containing gas flowing at between 1 slm to about 6 slm and the pressure of the remote plasma source generator is maintained at between 0.5 Torr to 20 Torr. Equation (1) shows the example of using NF₃ as the cleaning gas:



[0059] The fluorine radical (F^*) can also recombine to form fluorine gas (F_2), which does not have the same cleaning effect as the fluorine radical (F^*) for SiN film. The reduction of cleaning efficiency due to fluorine radical recombination is stronger on SiN film cleaning than on amorphous silicon film cleaning, since amorphous silicon can also be cleaned by thermal F_2 processing. Equation (2) shows the reaction of fluorine radical recombination.



The fluorine radicals can recombine before they reach the reaction chamber. Although not wishing to be bound by any theory, unless explicitly set forth in the claims, narrower passages in the diffusers and higher back pressure in plenum 264 could enhance fluorine radical recombination prior to entering the process volume 212 and could reduce the cleaning efficiency.

[0060] Table 2 compares the remote plasma source cleaning rates for SiN film and α -Si film deposited in a PECVD chamber under identical conditions for the three designs mentioned in Tables 2 and 3. The remote plasma source cleaning species is generated by flowing 4 slm Ar and 4 slm NF_3 into an ASTeX remote plasma source (RPS) generator that is maintained at 6 Torr. The ASTeX remote plasma source generator is made by MKS Instruments, Inc. of Wilmington, Massachusetts.

Film	Cleaning rate (Å/min)		
	Quad-aperture	0.055 in. Funnel	0.040 in. Funnel
SiN	7806	9067	7517
α -Si	5893	6287	5595

Table 2 compares the RPS clean rate of 3 types of diffuser designs for SiN and α -Si films.

[0061] The results show that 0.055 inch funnel shaped diffuser has the best cleaning performance, followed by the quad-aperture design and with 0.040 inch funnel being the last. The result is likely due to the lower back

pressure and less restrictive diffuser path of the 0.055 inch funnel diffuser compared to the quad-aperture and 0.040 inch funnel design, which results in less F* recombination and higher cleaning efficiency.

[0062] Table 3 shows the back pressure (Pb) of the RPS cleaning process when Ar flow is at 4 slm and NF₃ is between 0-4 slm, for both RPS plasma on and off conditions.

Flow (slm)	Pb (mTorr), Quad-aperture		Pb (mTorr), 0.055 inch Funnel		Pb (mTorr), 0.040 inch Funnel	
	Pb _{plasma-off}	Pb _{plasma-on}	Pb _{plasma-off}	Pb _{plasma-on}	Pb _{plasma-off}	Pb _{plasma-on}
0	1280	1280	930	930	1260	1260
1	1530	1840	1070	1310	1450	1730
2	1770	2370	1200	1650	1640	2150
3	2000	2850	1330	1940	1810	2530
4	2220	3300	1470	2210	1960	2880

Table 3 compares the back pressure of 3 types of diffuser design under different NF₃ flow and when RPS plasma is on and off.

[0063] The 0.055 inch funnel diffuser has lowest back pressure and has least F* recombination and highest SiN film clean rate. However, the back pressure of the quad-aperture design is higher than the back pressure of 0.040 inch funnel design and yet the cleaning rate of the quad-aperture design is higher than 0.040 inch funnel design. This shows that recombination due to pressure difference alone does not explain the cleaning rate result. The recombination in the diffuser also plays an important role.

[0064] Table 4 compares the narrowest diameters, lengths and volumes of the diffuser passages of quad-aperture and 0.040 inch funnel designs. The 0.040 inch funnel design has a larger passage volume compared to the quad-aperture design. The larger passage volume could allow additional fluorine radical recombination than in the narrow diffuser passage and affect the clean rate result.

	Quad-aperture	0.040 in. Funnel
Narrowest diameter in the diffuser passage (in.)	0.016	0.040
Length of narrowest diffuser passage (in.)	0.046	0.565
Volume of narrowest diffuser passage (in ³)	0.00001	0.00071

Table 4 compares the diameter, the length and the volume of the narrowest section in the diffuser for the quad-aperture and 0.040 inch funnel designs.

[0065] Clean rate is also dependent upon cleaning gas (such as NF₃) dissociation efficiency. Table 5 shows the chamber pressure (in the process volume 212) data of the three designs under RPS cleaning process. The chamber pressure for all three diffuser designs are all in a similar range.

Flow (slm)	Pc (mTorr), Quad-aperture		Pc (mTorr), 0.055 inch Funnel		Pc (mTorr), 0.040 inch Funnel	
	P _c plasma-off	P _c plasma-on	P _c plasma-off	P _c plasma-on	P _c plasma-off	P _c plasma-on
0	345	345	330	330	323	323
1	391	460	374	451	365	430
2	438	584	420	567	409	536
3	483	692	464	676	452	635
4	528	796	506	773	494	731

Table 5 compares the chamber pressure of 3 types of diffuser design under different NF₃ flow and when plasma is on and off.

[0066] NF₃ dissociation efficiency is directly proportional to the ratio of the net pressure increase when plasma is on to the net pressure increase when plasma is off. Table 6 shows the ratio of the net pressure increase when plasma is on to the net pressure increase when plasma is off for the quad-aperture, 0.055 inch funnel and 0.040 inch funnel designs. $\Delta P_{c\text{plasma-on}}$ represents the pressure difference between the chamber pressure under certain NF₃ flow to the chamber pressure under 0 NF₃ flow when the plasma is on.

Similarly, $\Delta P_{C_{\text{plasma-off}}}$ represents the pressure difference between the back pressure under certain NF_3 flow to the chamber pressure under 0 NF_3 flow when the plasma is off. The ratio of $\Delta P_{C_{\text{plasma-on}}}$ over $\Delta P_{C_{\text{plasma-off}}}$ quantifies the NF_3 dissociation efficiency. The dissociation efficiency decreases with the increase of NF_3 flow rate. The dissociation efficiency is highest for 0.055 inch funnel design, followed by the quad-aperture design and then 0.040 inch funnel design. The NF_3 dissociation efficiency data correlate with the cleaning rate data.

NF_3 flow rate (slm)	$\Delta P_{C_{\text{plasma-on}}} /$ $\Delta P_{C_{\text{plasma-off}}}$, Quad-aperture	$\Delta P_{C_{\text{plasma-on}}} /$ $\Delta P_{C_{\text{plasma-off}}}$, 0.055 in. Funnel	$\Delta P_{C_{\text{plasma-on}}} /$ $\Delta P_{C_{\text{plasma-off}}}$, 0.040 in. Funnel
1	2.50	2.75	2.55
2	2.57	2.63	2.48
3	2.51	2.58	2.42
4	2.46	2.52	2.39

Table 6 compares the ratio of the net pressure increase when plasma is on to the net pressure increase when plasma is off for the 3 designs.

[0067] In addition to cleaning efficiency, the impact of the diffuser design on the deposition performance should also be examined to ensure deposition performance meet the requirements. Table 7 compares the SiN and α -Si deposition uniformities and rates using the different diffuser designs under the same process conditions for the 3 diffuser designs. The SiN film is deposited using 600 sccm SiH_4 , 2660 sccm NH_3 and 6660 sccm N_2 , under 1.5 Torr and 3050 watts source power. The spacing between the diffuser plate and the support assembly is 1.09 inch. The process temperature is maintained at about 355 °C. The α -Si film is deposited using 1170 sccm SiH_4 and 4080 sccm H_2 , under 3.0 Torr and 950 watts source power. The spacing between the diffuser plate and the support assembly is 1.09 inch. The process temperature is maintained at 355°C.

Film	Quad-aperture		0.055 inch Funnel		0.040 inch Funnel	
	Uniformity (%)	Dep rate (Å/min)	Uniformity (%)	Dep rate (Å/min)	Uniformity (%)	Dep rate (Å/min)
SiN	3.8	1746	4.3	1738	3.2	1740
α -Si	3.9	1272	4.5	1261	4.4	1226

Table 7 compares the SiN and α -Si films deposition uniformities and rates for the 3 designs.

[0068] The results show that the deposition rates and uniformities of the three designs are relatively comparable. The deposition rates are about the same for the three designs. The uniformity of 0.055 inch funnel design is worse than the quad-aperture design. However, the uniformity can be improved by narrowing the diameter of the restrictive section 402 (0.040 inch vs. 0.055 inch). The uniformity of 0.040 inch funnel design (3.2% and 4.4%) is better than 0.055 inch funnel design (4.3% and 4.5%). For SiN film, the 0.040 inch funnel design (3.2%) is even better than the quad-aperture design (3.8%). Other film properties, such as film stress, reflective index, wet etch rate, are equivalent for the three designs. The results show that the film uniformity is affected by the diffuser design and can be tuned by adjusting the diameter of the restrictive section. The results also show that the funnel design can achieve the same deposition properties, such as uniformity, deposition rate, film stress, reflective index and wet etch rate, as the quad-aperture design.

[0069] In addition to the diffuser design, process pressure can also affect deposition rate and uniformity. Table 8 shows the effect of process pressure (or chamber pressure) on uniformity and deposition rate for 0.055 inch funnel design diffuser. Lower chamber pressure gives better uniformity and lower deposition rate.

Chamber pressure (Torr)	Uniformity (%)	Deposition rate (Å/min)
1.2	3.9	1545
1.5	5.5	1756
1.8	5.1	1784

Table 8 shows the deposition pressure, uniformity and deposition rate of SiN film using a 0.055 inch funnel design diffuser plate.

[0070] The funnel design diffuser plate is easier to manufacture compared to the quad-aperture design. Therefore, the yield and cost of manufacturing the funnel design diffuser plate would be improved. In addition to ease of manufacturing, the funnel design diffuser plate also has the benefit of less residual fluorine on the diffuser plate after RPS clean. This results in less fluorine incorporation in the gate dielectric films and improved device performance. The funnel design could have better or equivalent clean rate and efficiency compared to the quad-aperture design, depending on the diameter of the restrictive section 402 selected. The funnel design also could have deposition rate and uniformity performance equivalent to the quad-aperture design.

[0071] For flat panel display with larger surface area, diffuser plate 258 with larger top surface area 420 would be required. With the increase of top surface area 420, the thickness of the diffuser plate 258 could increase to maintain the strength in supporting the diffuser plate. Figure 8A shows a variation of the funnel design in Figure 4A for thicker diffuser plate. All the corresponding design attributes of Figure 8A are same as Figure 4A. The guidelines used to design the restrictive section 802, the flared section 806, and flaring angle 816 are similar the guideline used to design the restrictive section 402, the conical section 406, and flaring angle 816 of Figure 4A respectively. The presently preferred configuration of the flared section 806 is the conical cross-section shown in Figure 8A. However, other configurations including concave cross-sections, such as parabolic, and convex cross-sections, can be used as well. The difference between Figure 8A and Figure 4A is that Figure 8A is thicker by the 801 layer. A larger diameter section 804 can be created between the first side 818 of the diffuser plate 258 and the restrictive section 802. The large diameter section 804 is connected to the restrictive section 802 by a flared connector 803. During the manufacturing process of machining the restrictive section 802 and the larger diameter section 804, the flared connecting section 803 is created by using a different drill to round up (or

remove) the burrs left during drilling sections 802 and 804. Since the large diameter section 804 has larger diameter than restrictive section 802, it only slightly increase the manufacturing time and does not affect manufacturing yield. The diameter of the larger diameter section 804 should be at least 2 times the diameter of the restrictive section 802 to ensure that the addition of the larger diameter section also does not change the backpressure and chamber pressure during processing as compared to the funnel design in Figure 4A. Due to this, the deposition process and the qualities of the film deposited using the design in Figure 8A are similar to the deposition process and the qualities of the film deposited by the funnel design of Figure 4A. The larger diameter section 804 has a diameter between about 0.06 inch to about 0.3 inch. The edges of the larger diameter section 804 of the diffuser holes on the first side 818 of the diffuser plate 258 could be rounded. The ratio of the length 801 of the larger diameter section to the length 811 of the restrictive section 802 should be between about 0.3 to about 1.5. The total thickness of the diffuser plate, which equals the summation of length 801, length 811 and length 812, is between about 1.0 inch to about 2.2 inch.

[0072] Figure 8B shows an alternative design to the design shown in Figure 8A. During the manufacturing process of machining the restrictive section 802 and the flared section 806, a flared connecting section 805 could be created by using a different drill to round up (or remove) the burrs left during drilling sections 802 and 806. Aside from the addition of this connecting section 805, the rest of design attributes of Figure 8B are the same as the design attributes of Figure 8A.

[0073] Although several preferred embodiments which incorporate the teachings of the present invention have been shown and described in detail, those skilled in the art can readily devise many other varied embodiments that still incorporate these teachings.